

Dynamics and Microphysics in Marine Stratocumulus – FY07 Annual Report

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LONG-TERM GOALS

The Dynamics and Microphysics in Marine Stratocumulus (DMIMS) project encompasses two distinct overarching goals: (1) Examination of the structure and forcing of a Coastally Trapped Wind Reversal (CTWR) and (2) Examination of the role of mesoscale organization in marine stratocumulus and the interplay between cloud-microphysical processes, specifically the production and evaporation of drizzle, mesoscale circulations within the boundary layer, and spatial variability in cloud properties.

Understanding the forcing that controls the propagation and evolution of a CTWR event is essential for improving the modeling and prediction of CTWRs, which can disrupt operations along the coast due to the fog that accompanies these events. The sporadic occurrence of CTWRs has confounded several efforts to document the structure of these events using instrumented research aircraft. Only three CTWRs have been documented using instrumented aircraft: 10 – 11 June 1994 (Ralph et al., 1998; Nuss et al. 2000); 21-22 July 1998 (Nuss et al., 2000); and the 22-25 June 2006 CTWR (Parish et al., 2007). Of these, the 22-25 June 2006 dataset collected using the University of Wyoming King Air is the most extensive due to the suite of instruments onboard the King Air. A series of visible satellite images showing the progression of the 22-25 June 2006 event is shown in Figure 1.

The significant cooling effect of marine Sc on global climate due to the dramatic difference in albedo between the cloud layer and the underlying ocean surface has been recognized for several decades underlies much of the interest in the processes that determine the characteristics and evolution of the marine stratocumulus layers. Recent observations of these cloud layers using airborne or ship based radars have shown that drizzle in marine stratocumulus is both more common and stronger than had previously been realized (Albrecht et al., 1995; Vali et al., 1998; Stevens et al., 2003; Bretherton et al., 2004). As such, it is important to understand the myriad effects of drizzle on the characteristics, thermodynamic structure, and dynamics of the stratocumulus-topped boundary layer and, where possible, to quantify these effects. Effects of drizzle that need to be better quantified include not only the drizzle rate at cloud-base and at the sea surface, but also the rate at which Cloud Condensation Nuclei (CCN) are removed due to the collision-coalescence process – the leading sink term for CCN within the boundary layer (Wood, 2006).

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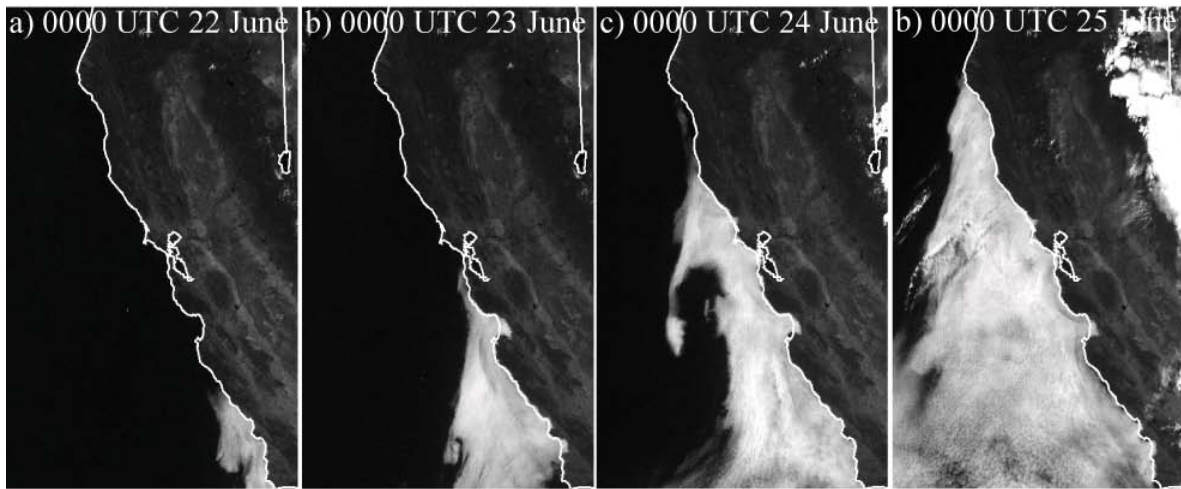


Figure 1. The progression of the 22-25 June CTWR as seen in visible (GOES) satellite imagery. Images a – d show the 0Z satellite images on June 22nd, 23rd, 24th, and 25th respectively.

OBJECTIVES

The dataset collected during the DMIMS field campaign is being used to document the structure of the 22-25 June CTWR. This data is being used in conjunction with numerical simulations to examine the critical forcings. Understanding the role of radiative forcing associated with the cloud layer in driving the propagation of the CTWR is of particular interest.

Data collected during the drizzle-cell flights is being used to document the structure of mesoscale organization within the stratocumulus-topped boundary layer and to investigate the interplay between drizzle and mesoscale organization. Radar and in situ cloud-microphysics data from these flights will also be used to make quantitative estimates of the rate at which CCN are lost due to coalescence during the drizzle formation process. This estimate depends not only on the cloud-base drizzle rate, but also on the size of the collected cloud-droplets (and therefore the vertical profile of the accretion of cloud water).

APPROACH

The University of Wyoming (UW) King Air research aircraft was used to collect a comprehensive dataset combining in situ and remotely sensed measurements during a 6-week deployment to the coast of Northern California. The UW King Air conducted approximately 25 research flights from the base of operations in Arcata, CA. Instrumentation onboard the UW King Air included the Wyoming Cloud Radar in addition to standard in situ measurement of temperature, winds, and cloud- and precipitation particle size spectra. In addition the UW King Air carried redundant instruments (differential-GPS and radar altimeters) for highly accurate, pressure-independent measures of aircraft altitude that allow atmospheric pressure gradients and perturbations to be measured. The King Air also carried a suite of aerosol instrumentation for measurement of CCN, Condensation Nuclei (CN), and Ultrafine aerosol.

The CTWR flights consisted of isobaric legs at several levels across the leading and lateral edges of the CTWR in order to measure the thermal and pressure gradients document changes in the winds. In

addition to the isobaric flight legs, a series of sawtooth flight legs were carried out in order to document the vertical structure of the disturbance. The analysis of the 22-25 June 2006 CTWR is being carried out by David Rahn, a Ph.D. candidate in the UW Atmospheric Science Department, under the guidance of Professor Thomas Parish.

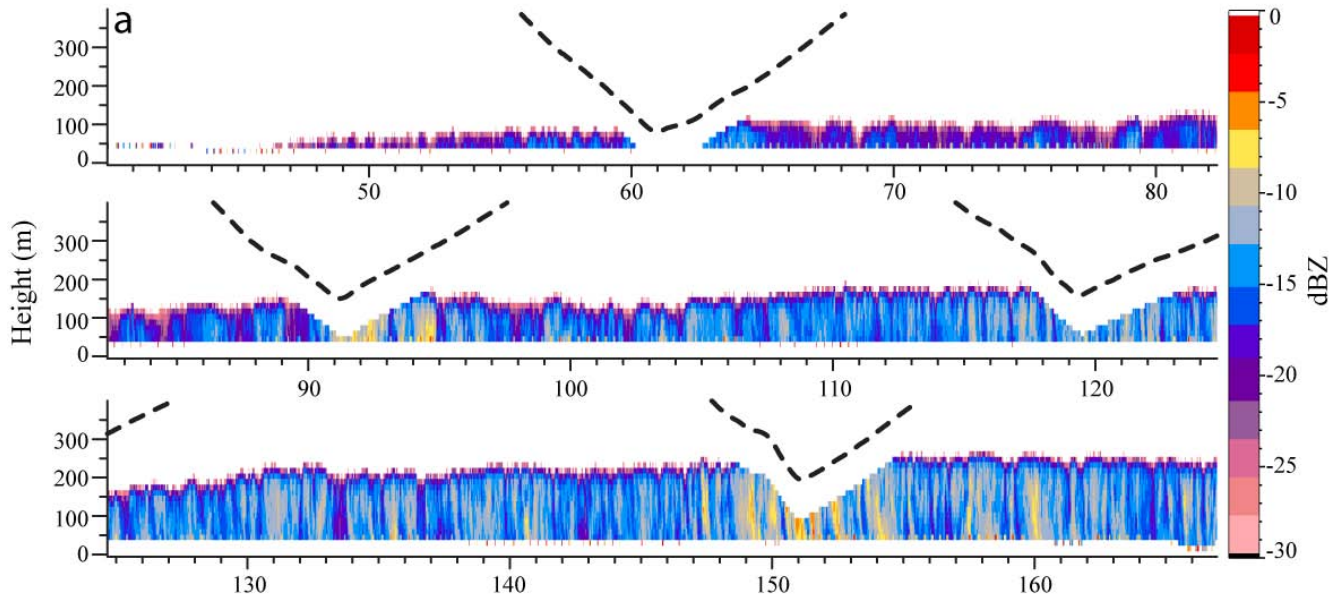


Figure 2. WCR data from one of the coast-parallel saw tooth flight legs showing the increasing depth of the cloud layer from NW-SE. Distance is measured from the NW end of the flight leg as described by Parish et al., 2007. Dashed line marks the aircraft flight altitude. The V-shaped bites out of the cloud layer are the result of the 125m dead-zone of the WCR impinging on the cloud layer.

The drizzle cell flights consisted of repeated flight legs at a range of altitudes through a single mesoscale feature. Each drizzle cell flight consisted of about a dozen legs with a typical duration of ~2 hours within a single drizzle-cell. Flight legs were conducted at four or five different altitudes: approximately 100m above the ocean surface, just below cloud base, in cloud, and ~200m above cloud top. The flight legs were allowed to advect with the cell thereby allowing the evolution of the cells to be documented. The flight track for one of the drizzle-cell flights (June 29, 2006 flight ‘a’) is shown in Figure 3. The analysis of the WCR and in situ data from the ‘drizzle-cell’ flights is being carried out by Co-PI David Leon and Dr. Jefferson Snider. Dr. Snider is also analysing the aerosol data from DMIMS with the assistance of Binod Pokharel, a M.S. student in the UW Atmospheric Science Department. Drs. Snider and Leon, with assistance from B. Pokharel will be working on estimation of the CCN scavenging rate.

WORK COMPLETED

Aircraft and airborne radar data from the DMIMS field campaign have been analyzed. This includes data from the Wyoming Cloud Radar, aerosol and CCN instrumentation, as well as standard cloud-microphysics data. One paper describing observations of the structure of the CTWR on June 22-25 has been submitted and is now in press (Parish et al, 2007). A second paper investigating the forcing of the June 22-25 CTWR is currently in review (Rahn and Parish, 2007).

An additional paper, in which a theoretical underpinning for the existence of a threshold radar reflectivity above which drizzle is expected in marine stratocumulus is presented, has also been accepted for publication (Liu et al., 2007). This paper which uses cloud-microphysics and radar data from DMIMS and an earlier marine stratocumulus field campaign using the UW King Air extends a previous analysis by Wang and Geerts (2003)

A paper describing the drizzle-cell observations based on four cases collected during DMIMS is currently being prepared and it is expected that this paper will be submitted to Monthly Weather Review before the end of the year.

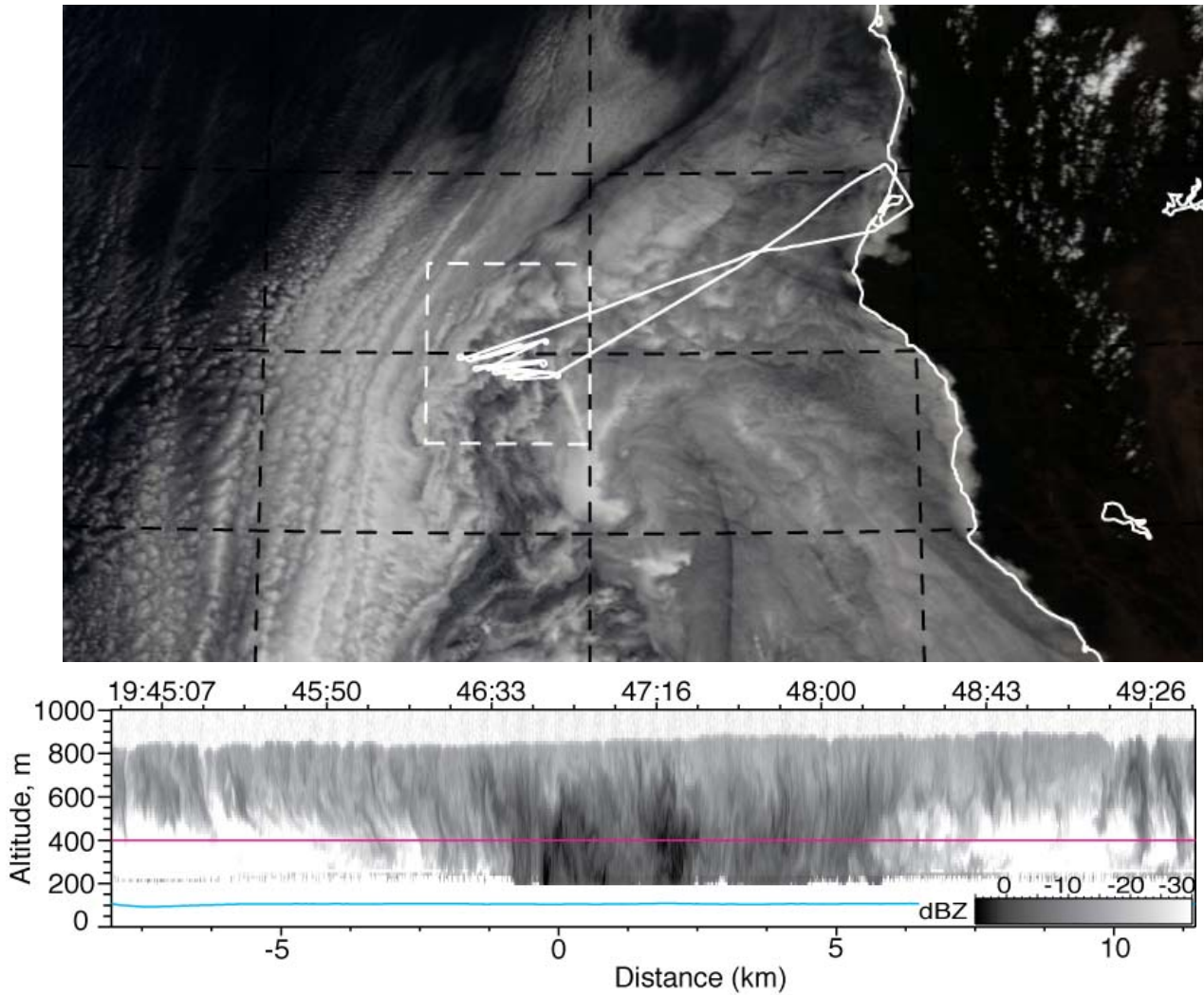


Figure 3. (Top) MODIS visible image showing the stratocumulus field sampled on June 29, 2006. The flight track of the UW King Air is shown in white. The flight legs appear staggered due to the advection of the cloud field – in an air relative frame they are stacked. (Bottom) Vertical cross-section of radar reflectivity from the WCR showing the high-reflectivity ‘core’ of the cell. Colored lines indicate the altitudes of the near-surface and sub-cloud flight legs.

RESULTS

Significant results from the DMIMS CTWR study include recognition that longwave radiative cooling from the cloudy tongue helps maintain the wind reversal and . While the cloud tongue adjacent to the coast is the signature feature of a CTWR few previous studies, with the notable exception of Thompson et al. (2005), have considered the role of cloud forcing. Because the cloud layer is so shallow (observed cloud-top heights during the 22-25 June CTWR were < 225 m), longwave radiation can cool the layer at a rate of $> 1 \text{ K hr}^{-1}$. Thus, even if air within the CTWR is initially warmer than the ocean surface temperature, radiative cooling would reduce the temperature within the CTWR to below that of the ocean surface within a few hours. Numerical simulations of the June 22-25, 2006 CTWR

show that the inclusion of longwave radiative forcing by the cloud layer is necessary to reproduce the observed propagation of the disturbance (Rahn and Parish, 2007).

Due to atypical conditions during June 2006 the UW King Air was able to sample a number of large (> 25km diameter) mesoscale structures which are frequently observed in to the west of 130° W, but which are uncommon closer to the US West coast. Key features of these cells include a bright core, surrounded by a lower-albedo shield region, a poorly mixed subcloud layer that is strongly coupled to the cloud layer in the center of the cell. These observations differ dramatically from the shallow, well-mixed boundary layer observed during DYCOMS-II (Stevens et al., 2003) but are similar to observations from ASTEX (Miller and Albrecht, 1995; Kropfli and Orr, 1993). The ASTEX observations, however, were limited to observations from ground-based radars, radiometers, and radiosondes. A MODIS visible image showing the variety of mesoscale features encountered, and a reflectivity cross-section from the same flight are shown in Figure 3.

Among other notable advances, the ability to obtain high-accuracy, pressure-independent measurements of aircraft altitude have allowed us to resolve the height (pressure) perturbations that help drive the mesoscale circulation. These perturbations, which allow the mesoscale circulation to overcome the stability resulting from the evaporation of drizzle, are on the order of 0.5 m (0.05 mb). Observed height perturbations as a function of flight altitude from the June 29th, 2006 flight are shown in Figure 4.

IMPACT/APPLICATIONS

The observations of the 22-25 June 2006 CTWR described in Parish et al. (2007) provide a well-documented case that can be used to evaluate the fidelity with which numerical simulations are able to reproduce the key features and timing of the CTWR. Already, as discussed in Rahn and Parish (2007), it is clear that greater attention needs to be paid to the effects of the cloud field. Both the radar reflectivity values and the structure of the reflectivity field indicate the presence of drizzle despite the shallowness of the cloud layer. Because of the shallowness of the cloud layer, even weak drizzle could significantly impact the cloud characteristics (both through the removal of cloud-water and coalescence-scavenging of CCN). Thus, it may be worthwhile to include basic parameterizations of precipitation in future numerical simulations of CTWRs.

The difference in the scale and apparent significance of mesoscale organization encountered during DMIMS as compared to DYCOMS-II along with the similarity of DMIMS observations to those collected during ASTEX hints that boundary layer depth may be the critical factor in determining how the boundary-layer is affected by drizzle. During DYCOMS-II the boundary layer was shallow (<1km), relatively well-mixed, with only small variations in cloud properties such as cloud droplet number concentration within individual mesoscale cells (DYCOMS flights RF02 and RF04 are exceptions to these statements). In contrast, during DMIMS the boundary layer was deeper (~1.25 km), poorly mixed, and showed variations of a factor of four or more in cloud droplet number concentration and liquid water content between the cores and edges of the cells. The upcoming VOCALS-REx field campaign, which will be conducted in the climatologically-deeper South-Eastern Pacific stratocumulus region will provide data to help support or refute the importance of boundary-layer depth in determining the response to drizzle.

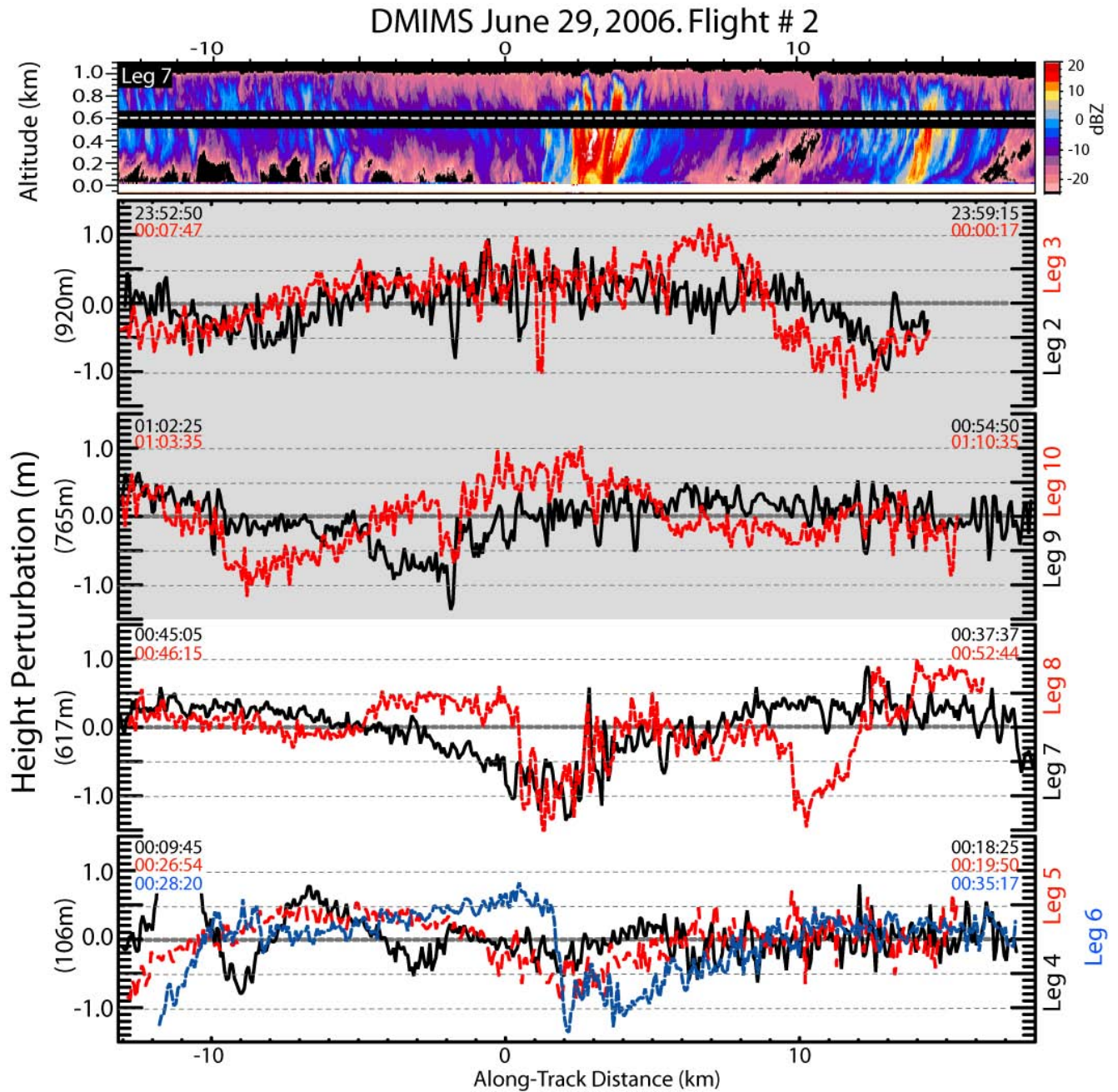


Figure 4. Height perturbations from the June 29, 2006 drizzle-cell flight. Plots are stacked by flight altitude with the shaded region indicating the cloud layer. The background pressure gradient has been estimated and removed in order to allow the perturbations to be seen more clearly. A negative height (pressure) perturbation is evident near the center of the cell below cloud with a positive height (pressure) perturbation within the cloud layer with the largest perturbations occurring below cloud and at cloud top. Thus, the pressure gradient is directed upward in the subcloud layer, thereby helping parcels overcome negative buoyancy due to evaporative cooling by drizzle, and downward within the cloud layer, thereby driving the divergence away from the cell core within the cloud layer.

RELATED PROJECTS

Planning is currently underway for a field campaign that compliments and will extend the marine stratocumulus studies undertaken during DMIMS. The VOCALS-REx field campaign, scheduled for late-2008, will be the first comprehensive study of stratocumulus in the South-Eastern Pacific Region. The VOCALS-REx field campaign is based on observations to be collected from multiple aircraft and ship platforms and is supported by several agencies including NSF, ONR, and DOE. Descriptions of the VOCALS-REx hypotheses, observing platforms, and plans can be found on the web at: http://www.atmos.washington.edu/~robwood/VOCALS/vocals_uw.html

DMIMS investigators Drs. David Leon and Jefferson Snider have submitted a proposal to NSF to deploy the Wyoming Cloud Radar, Wyoming Cloud Lidar, and aerosol instrumentation for measurement of the concentrations of Ultrafine aerosol and Cloud Condensation Nuclei (CCN). Conditions in the South-Eastern Pacific, where the boundary-layer depth is typically 1 – 1.5 km, deeper than the typical boundary layer in the North-Eastern Pacific stratocumulus region, but comparable to the abnormally-deep boundary layer observed during the DMIMS drizzle-cell flights.

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